THE HYDROLOGIC CYCLE IN BEDE'S *DE NATURA RERUM*

Lin Ferrand

The man who came to be known as the Venerable Bede was born in 672 A.D. in the region around the mouths of the Tyne and Wear rivers in Northumbria. He entered the monastery at Wearmouth at the age of seven and was soon transferred to the brother monastery at Jarrow where he lived for the rest of his life. Amply supplied with classical texts by the adventurous abbots of his community and with a lifelong commitment to teaching and learning, he went on to become the foremost European scholar of his age.

It is generally believed that Bede wrote his secular treatise *De natura rerum*[1] in 703 A.D. The work is closely modeled on an earlier work of the same title written in the early seventh century by Isidore of Seville.[2] However, it has often been noted that Bede did not copy slavishly from Isidore. He omitted nearly all of his religious and metaphorical material, simplified the presentation of the remaining natural historical material, and supplemented it with information found in the thirteenth book of Isidore's *Etymologies*,[3] the second book of Pliny the Elder's *Natural History*,[4]

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[1] Bede, *De natura rerum*, in John A. Giles, ed., *Opera quae supersunt omnia, nunc primum in Anglia, ope codicem manuscriptorum editionumque optimarum*, vol. 6. (London, 1843), pp. 100–122, hereafter cited as *De natura rerum*. The author wishes to thank Luca Grillo, Ph.D. candidate in the Department of Classics, Princeton University, for his assistance in translating the chapters of *De natura rerum* cited in this paper.

[2] Isidore of Seville, *Traité de la nature*, ed. and trans. Jacques Fontaine, (Bordeaux, 1960), hereafter cited as *Traité*.

[3] "Acerca del mundo y sus partes" in Isidore of Seville, *Etimologías*, vol. 2, book 13, ed. and trans. José Oroz Reta and Manuel A. Marcos Casquero Isidore of Seville, (Madrid, 1983), hereafter cited as *Etimologías 13*. This work was described and extracts translated in Ernest Brehaut, "An Encyclopedist of the Dark Ages: Isidore of Seville," *Studies in History, Economics and Public Law*, 48, no. 1 (1912), 15–270, hereafter cited as *Encyclopedist*. Digital version of *Encyclopedist* available at http://bestiary.ca/etexts/brehaut1912/brehaut1912.htm.

[4] Pliny the Elder, *Natural History, Book 2: An Account of the World and the Elements*, ed. and trans. John Bostock and H.T. Riley (London, 1855), hereafter cited as *Natural History 2*. Digital version available at http://www.perseus.tufts.edu/cache/perscoll_Greco-Roman.html).

and occasionally the writings of the Church Fathers.[5] According to Smyth[6] and others, he also used material from a source long believed to have been written by Isidore but now thought to have been written in late seventh-century Ireland by an author often referred to as "Pseudo-Isidore."[7] Some have claimed that Bede did not hesitate to use his observations of his surroundings as a basis for emending his classical sources.[8] It is important to ask whether his choices were consistent with what he could have observed in his own time and place—rather than with our constantly-evolving view of scientific truth—in order to evaluate the degree to which this is demonstrated in *De natura rerum*.

In a widely-read book on the Anglo-Saxon period, Wormald describes the joint monastic communities of Wearmouth (founded 674 A.D.) and Jarrow (founded 681–2 A.D.) as "an island of Mediterranean culture in a barbarian sea" during the late seventh and early eighth centuries.[9] Not only did the founder of the twin monasteries make several trips to Rome to bring back manuscripts as well as experts in masonry, manuscript production, and chanting techniques; there were also local examples of Roman building techniques, e.g., Hadrian's Wall and associated structures located just across the Tyne from Jarrow, which supplied materials as well as models for the monasteries' construction.[10] However, whatever the religious and intellectual lives of the monastic elite and the buildings in which they lived and worshiped, their physical environment in the Tyne and Wear estuaries was very different from that found along the coast of the Mediterranean. Some disparities, e.g., greater seasonal variability in the length of daylight can be attributed to the difference in latitude. Others result from a combination of latitude, geological history and/or persistent atmospheric and oceanic

[5] Charles W. Jones, "Manuscripts of Bede's De Natura Rerum," *Isis*, 27, no. 3 (1937), 430–440.

[6] Marina Smyth, *Understanding the Universe in Seventh-Century Ireland* (Woodbridge, UK, 1996), hereafter cited as *Ireland*.

[7] Pseudo-Isidore (unknown seventh-century Irish author), *Liber de ordine creaturarum*, ed. and trans. Manuel C. Diaz y Diaz (Santiago de Compostela, 1972), hereafter cited as *Creaturarum*.

[8] See, for example, Faith Wallis, *The Reckoning of Time* (Liverpool, 1999), pp. 307–312 for a discussion of Bede's use of tidal data collected along the coast of Britain, hereafter cited as *Reckoning*.

[9] Peter Wormald, "The Age of Bede and Aethelbald," in *The Anglo-Saxons*, ed. James Campbell (London, 1991), p. 75.

[10] Rosemary Cramp, *Wearmouth and Jarrow Monastic Sites*, Vol. 1 (London, 2006), pp. 23–27, hereafter cited as *Wearmouth*.

circulation patterns. These include cooler water and air temperatures, heavier soils, contrasting vegetation types, and less seasonal variability in rainfall. This essay will focus on the relationships between sections of Bede's *De natura rerum* that described aspects of the environment that comprise the so-called hydrologic cycle and its known textual sources. Its goal will be to assess the degree to which observation informed Bede's decisions to include, omit, revise, and/or to add to material found in Isidore's *De natura rerum*.

The Local Environment

The time at which Bede wrote his *De natura rerum* was long enough ago that we must ask whether the climate in northeast England was significantly different from the climate today. In her recent book, Petra Dark summarized the evidence for the climate in first millennium A.D. Britain using a variety of paleoclimatological techniques, including study of textual sources, ice cores, glacial movement and glacial lake sediments, tree rings, and peat stratigraphy.[11] While all the evidence seems to point to a warmer period in the second and third centuries of this era, there is little agreement regarding the centuries between 500 and 800 A.D. For the relatively brief period in which Bede lived before writing *De natura rerum*, the evidence appears to be contradictory. According to Dark, glacial movement data from Scandinavia suggests that this period was cooler, while data from glacial lake sediments in Switzerland and Norway suggest that is was warmer. Tree ring data suggests a period of relative warmth after 750 A.D. but does not indicate a deviation from current conditions earlier in the eighth century. In addition, peat stratigraphy, for which there is more local data, is notoriously difficult to interpret. One of the earliest peat studies in northern England concluded that warmer, drier conditions began in the second and extended through the seventh century. However, other studies suggested a wetter period in the sixth and seventh centuries. More recent peat studies have provided similarly inconclusive results for this period. For example, R.C. Chiverrel found that there was a change to a wetter or cooler climate between 670 and 980 A.D. but

[11] Petra Dark, *The Environment of Britain in the First Millenium AD* (London, 2000), pp. 19–28.

that this was preceded by a warmer or drier period between 650 and 860 A.D.,[12] time periods that unfortunately overlap during the period of interest. Given the ambiguity of our current understanding of late seventh century Northumbrian climate and the lack of a firm basis for concluding otherwise, one can assume that the climate Bede experienced was approximately the same as the twentieth century climate in the Tynemouth region.[13]

The monastery at Jarrow was situated, like its predecessor at Wearmouth, at a site where a river flows into the North Sea. That being the case, we must also ask whether local sea level has changed significantly during the intervening years. While there has been a substantial worldwide rise in sea level during the Holocene era (approximately the last ten to eleven thousand years), it is generally believed to have been relatively constant during the last 1,500 years.[14] Isostatic rebound has also been a significant factor in local sea level change along some portions of the British coast. The last glaciation covered Scotland, which continues to rebound upward since the ice disappeared, but not southern England, which continues to sink as the island restabilizes. Data reported by W.R. Peltier[15] illustrate the effects of this restabilization. While the mean sea level relative to the coast has fallen in the area near Dundee on the east coast of Scotland in the last 1500 years, it has simultaneously risen in the area around the Fenlands. Given its location between these points, the area around the mouth of the Tyne has probably not experienced a significant change in relative mean sea level during that time.

Given these conclusions and despite the fact that this area has been continuously altered by its inhabitants since Bede's time, it is reasonable to assume that the site of the monastic community of Jarrow was

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[12] R.C. Chiverrell, "A Proxy Record of Late Holocene Climate Change from May Moss, Northeast England," *Journal of Quartenary Science*, 16 (2001), 9–29.

[13] Weather data averaged over thirty-year periods as prescribed by the World Meteorological Organization are available online from the Met Office of the UK Ministry of Defense at http://www.metoffice.gov.uk/climate/uk/averages/index.html. Data include monthly maximum and minimum temperatures, days of air frost, hours of sunshine, rainfall depth, days with rainfall depth of at least one millimeter, and wind speed at ten meters above the ground surface. However, as we currently appear to be in a period of relatively unstable climate, I will avoid using data collected in the last ten to fifteen years whenever possible. Averaged data for 1969–1990 are used throughout this essay.

[14] Chiverrell, 14. E.g., estimates for post-glacial sea level change at http://en.wikipedia.org/wiki/Sea_level_rise.

[15] W. Richard Peltier, "Postglacial Variations in the Level of the Sea," Reviews of Geophysics, 36 (1998), 603–689.

situated, then as now, beside a tidal estuary, i.e., along a stretch of the river that was invaded by sea water at each high tide. It may well have been surrounded by what we currently refer to as 'wetlands,' i.e., areas of land that are submerged for at least part of the day. The tidal wetland that was known as Jarrow Slake survived (despite much earlier proposals to fill it)[16] until the 1970s. Saxon-era buildings extending from the church of St. Paul at the northwest corner of the site down to the edge of the Tyne's flood plain in the south were excavated by Rosemary Cramp.[17] Even without its persistent rainfall (discussed below) Bede's environment would have been consistently damp.

On the other hand, life at Jarrow would not have been as cold as its latitude suggests. The climate of the British Isles is profoundly affected by its surrounding seas, the most marked effect being the moderation of temperature. Despite the fact that it is further north than Edmonton in Canada (55°N vs 53°N), winter temperatures at Jarrow are considerably warmer while summers tend to be cool. Monthly averages of high and low temperatures for the period between 1961 and 1990 are shown in figure 1. In the absence of data for Jarrow itself, I have included data for Boulmer[18] (approximately thirty miles to the north) and Durham[19] (situated on the banks of the Wear River approximately fifteen miles to the south). The results are consistent with data collected between 1881 and 1915, published for the US military during WWII and declassified in 1946, which indicate that the average daily temperature range was about 10°F on the east coast of England.[20]

Nor would the cumulative depth of rainfall in an average year at Jarrow be as great as one might expect. Due to the prevailing westerly winds in the northern hemisphere and the spine of hills that extends north-to-south through central northern England, annual rainfall on the northeast coast of England is significantly less than on its west

[16] See, for example, William Armstrong's arguments against a contemporary proposal to fill Jarrow Slake in his *Observations on the Improvement of the Tyne* (Newcastle Upon Tyne, 1836), pp. 4–8.

[17] Rosemary Cramp, "Monkwearmouth and Jarrow: The Archaeological Evidence," in *Famulus Christi: Essays in Commemoration of the Thirteenth Centenary of the Birth of the Venerable Bede*, ed. Gerald Bonner (London, 1976), pp. 5–18; Cramp, *Wearmouth*, p. 18.

[18] Averaged data from the weather station at Boulmer can be found at http://www.metoffice.gov.uk/climate/uk/averages/19611990/sites/boulmer.html.

[19] Averaged data from the weather station at Durham can be found at http://www.metoffice.gov.uk/climate/uk/averages/19611990/sites/durham.html.

[20] Air Forces Weather Research Center, *Climate and Weather of the British Isles*, vol. 6, no. 2, US Army Weather Directorate, 1942, hereafter cited as *Climate and Weather*.

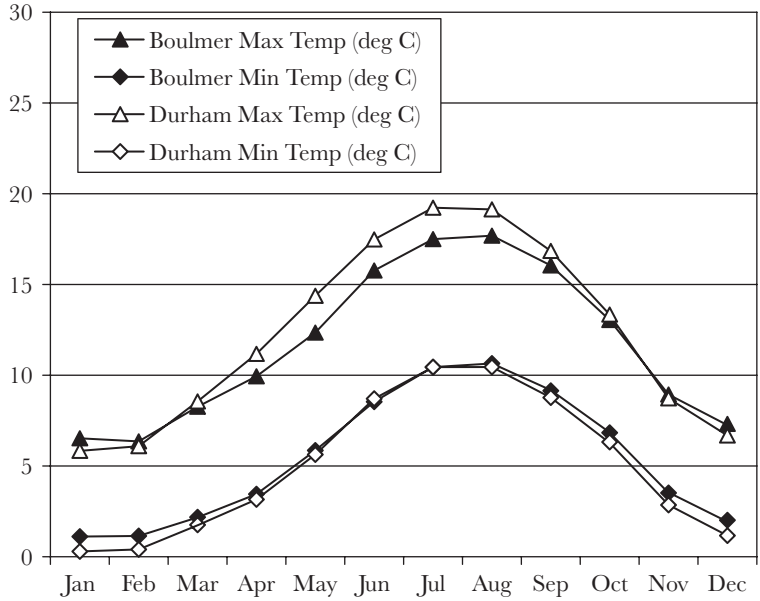

Figure 1. Average monthly temperature extremes (1961–1990): monthly average temperature minima and maxima in the region around Jarrow.

coast. Average annual rainfall in the region of interest is approximately twenty-six inches.

The most significant difference between the climate at Jarrow and typical Mediterranean climates, also found on the southwest coast of Australia and around Capetown and San Francisco, is the lack of seasonality in the rainfall rate at Jarrow. (The climate found along the southern coast of Europe has distinctive properties that have come to be associated with a climate type now known as 'Mediterranean'.) While average temperatures may vary considerably from one Mediterranean climate to another, depending, for example, on altitude, they are all characterized by the concentration of nearly all rainfall into a winter rainy season. This difference is clearly illustrated in figure 2 which shows monthly average rainfall depths for Boulmer, Durham,[21] and San Francisco.[22]

If the assumption that environmental conditions at Jarrow in the late seventh century were approximately duplicated in the twentieth

[21] See notes 17 and 18.

[22] Monthly rainfall depth for 1960 through 2006 is available online from Golden Gate Weather Services at http://ggweather.com/sf/daily.html.

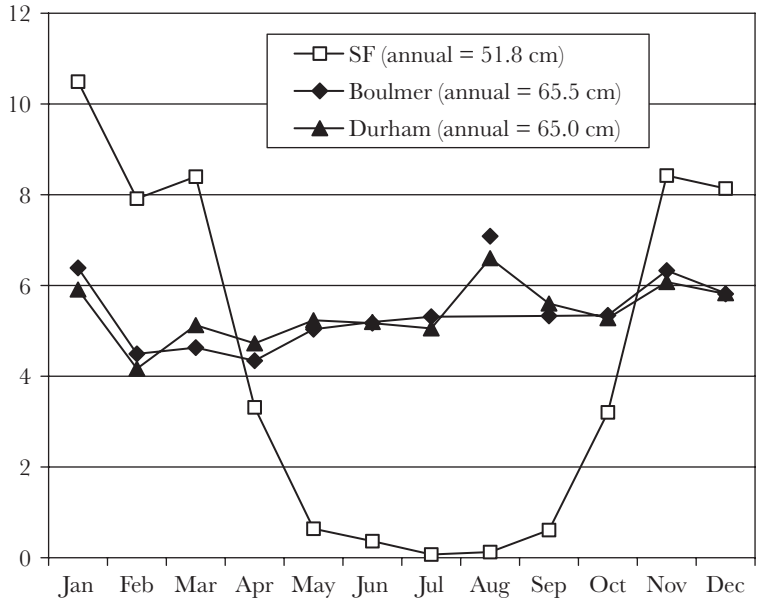

Figure 2. Average monthly rainfall (1961–1990) in the region around Jarrow (Boulmer and Durham) and in a typical Mediterranean climate (San Francisco).

century is correct, one can use available data to test the hypothesis that some of choices that Bede made in adapting Isidore's work were based on his own experience. A systematic formulation of these environmental conditions as components of the hydrologic cycle provides a useful tool for this analysis. This conceptual model, outlined below, will allow us to identify sections of Bede's *De natura rerum* that describe specific hydrologic processes and to compare each of these sections to the relevant data.

The Hydrologic Cycle and the Elements

The hydrologic cycle (figure 3) is made up of a series of processes in which water moves and changes its state (ice-liquid-vapor) to produce the phenomena referred to as 'weather' in the short term or 'climate' in the longer term. The cycle is driven by energy from the sun which causes water (mostly from the sea and other open water bodies but also from the land surface) to evaporate, i.e., to change state from liquid to gas and rise into the atmosphere where it may be transported long

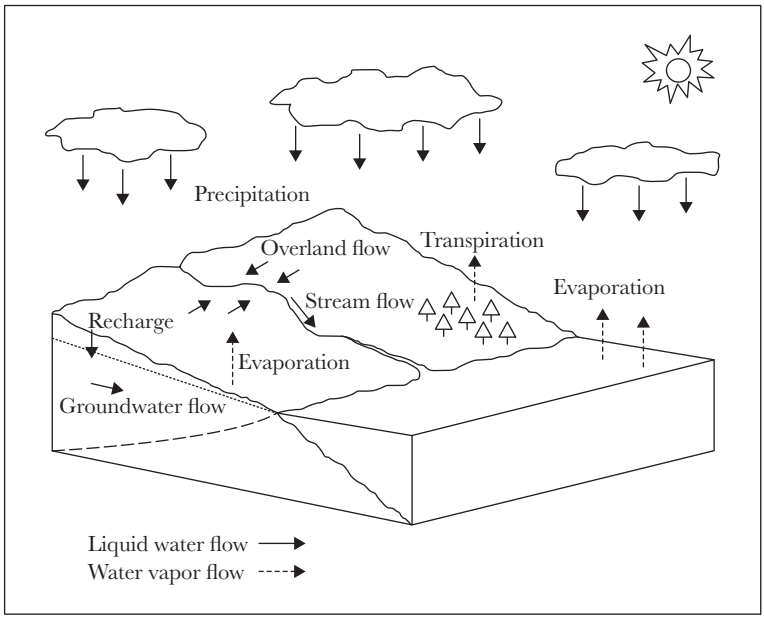

Figure 3. Schematic representation of the hydrologic cycle.

distances by winds. Atmospheric water vapor eventually condenses and/or freezes, i.e., changes state from gas to liquid and/or solid, to form clouds that may precipitate as rain, snow, sleet, or hail. Upon reaching the ground and melting if it arrives in solid form, precipitated water will either flow over the land's surface to join flowing streams and rivers or infiltrate through the ground surface. Infiltrated water may reevaporate from the soil's surface or be taken up by the roots of plants which eventually transpire it as vapor into the atmosphere, or it may continue moving downward to contribute to subsurface flow. Whether on the surface or underground, water in liquid form flows downhill under the force of gravity eventually to rejoin the sea.

We begin our analysis of Bede's revisions of Isidore by comparing their descriptions of the elements and possible transformations from one element to another. For the purposes of hydrological analysis, one might refer to the four classical elements of earth, water, air, and fire as 'states of matter.' The analogy between earth-water-air and the standard earthly states of solid-liquid-gas or ice-water-vapor is obvious. The state that might be considered analogous to fire, i.e., plasma, does not exist naturally on earth but is the substance of the sun that provides the energy to drive hydrologic processes. While this may be pushing the analogy farther than is necessary or useful, the coincidence

of the first three elements with the states of water as it moves through the hydrologic cycle is clear.

Isidore's *De natura rerum* gave two differing versions of the properties and interactions of the elements.[23] The first assigned the contrasting properties of thinness versus thickness, mobility versus immobility, and sharpness versus roundness. In this view, fire is thin while air, water, and earth are thick. Fire, air, and water are mobile while earth is immobile. Fire and air are sharp while water and earth are round. Isidore's second version, attributed to Ambrose, assigned a more limited set of properties to the elements: humidity versus dryness and hotness versus coldness. Air and water are humid while earth and fire are dry; fire and air are hot while water and earth are cold. In this version, these attributes were assigned such that every property belonged to two elements, closing the circle of the elements in a manner that was compared to dancers in a ring.

Bede adopted Isidore's second version in his description of the properties of the elements.[24] However, he added and emphasized the relative heaviness of the elements and their resulting relative positions. In Bede's view earth, as the heaviest element, cannot be sustained by any other and naturally takes the lowest position. Water is as much lighter than earth as it is heavier than air. Air, if placed in a vessel that is submerged in water, will rise immediately to the surface. Fire seeks without rest for its natural place above the air but may be suffocated by and vanish into air—a confusion arising from the fact that Bede is referring here to the glowing gases of earthly combustion rather than to the plasma of the sun—before it succeeds. He accounted for obvious exceptions to the general rules of position by noting that their ability to interact around the circle of elements is the reason that we see fire on earth and clouds and earthly objects in the air.

Bede's concepts of the relative heaviness and relative positions of the elements do not appear to originate in the works of Isidore or of Pseudo-Isidore. His ideas, however, may have derived from Pliny who said of the four elements:

> The highest of these is supposed to be fire, and hence proceed the eyes of so many glittering stars. The next is that spirit, which both the Greeks and ourselves call by the same name, *aera*. It is by the force of this vital principle, pervading all things and mingling with all, that the earth, together with the fourth element, water, is balanced in the middle of

[23] "Des éléments du monde," *chapter* 11 in Isidore, *Traité*.
[24] "De elementis," *chapter* 4 in Bede, *De natura rerum*.

> space. These are mutually bound together, the lighter being restrained by the heavier, so that they cannot fly off; while, on the contrary, from the lighter tending upwards, the heavier are so suspended, that they cannot fall down. Thus, by an equal tendency in an opposite direction, each of them remains in its appropriate place, bound together by the never-ceasing revolution of the world, which always turning on itself, the earth falls to the lowest part and is in the middle of the whole, while it remains suspended in the center, and, as it were, balancing this center, in which it is suspended. So that it alone remains immoveable, whilst all things revolve round it, being connected with every other part, whilst they all rest upon it.[25]

Consistent with his practice of using less complex language than his sources and making material as accessible as possible to his students, Bede adopted a simplified version of Pliny's treatment of the elements and added a concrete example—an air-filled vessel that bobs to the surface—from common experience. Bede's view of the significance of the relative weights and natural positions of the solid, liquid, or gaseous states of water will be apparent in his descriptions of the hydrologic processes.

Clouds and Rain

Bede[26] adopted, although in condensed form, Isidore's[27] essentially correct description of evaporation, cloud formation, and precipitation as rain. Although Isidore seemed to favor the idea that rain water derives from sea water, he noted that some believe that vapors exhaled by the ground also contribute. In his *Etymologies*, he apparently accepted this belief and said that rains derive from exhalations from earth and sea.[28] Bede correctly favored the later view that air lifts characteristically light water vapor from both earth and sea.[29] He agreed that water vapor in the atmosphere gathers together to form clouds; however, Bede correctly added[30] that the condensed droplets must remain small in order to remain suspended in the air. Neither Isidore in his *Etymologies* nor Pliny, whose interest seemed to have been in objects more exotic than

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[25] "Of the elements and the planets," *chapter* 4 in Pliny the Elder, *Natural History*, 2.
[26] "De nubibus" and "De imbribus," chapters 32 and 33 in Bede, *De natura rerum*.
[27] "Des nuages" and "Des pluies," chapters 32 and 33 in Isidore, *Traité.*
[28] Brehaut, *Encyclopedist*, p. 238.
[29] "De nubibus" in Bede, *De natura rerum*.
[30] "De nubibus" in Bede, *De natura rerum*.

water falling from the sky,[31] mentioned the importance of the size of atmospheric water droplets. However, Pseudo-Isidore noted that air is capable of keeping water droplets suspended as long as they remain miniscule (*in minutissimus guttis*).[32] Given Bede's emphasis on the relative heaviness of the elements and their natural positions, it is not surprising that he adopted this view to explain the presence of liquid water suspended in air and noted that it must return to its rightful place between earth and air as it gathers together.

In his chapter on rain,[33] Bede reiterated the importance of droplet size when he said that rain drops formed from clouds, where small drops merge into bigger drops until the air can no longer support them. But Bede's understanding of the process was called into question when he repeated Isidore's claim that the merging of cloud droplets resulted from the effects of wind or sun. In fact, both wind and sun promote evaporation rather than condensation or an increase in droplet size. However, in keeping with our emphasis on what was observable, it is relevant to remember that the arrival of a rainstorm is frequently heralded by a perceptable increase in wind. One might, therefore, attribute Bede's decision to retain Isidore's explanation to personal observation of a correlation between wind and precipitation.

Both Bede and Isidore commented on the rather remarkable fact that salty sea water becomes fresh rain water during the hydrologic processes described above. Isidore simply and accurately attributed this to distillation by the fire of the sun; dissolved solids are left behind when water is evaporated from the sea. Bede adopted this idea but incorrectly added that the conversion from salt to fresh water could also be caused by movement through the atmosphere as vapor after evaporation had taken place.[34] In addition, Bede's somewhat puzzling assertion that water could be changed from saline to fresh by pouring it on earth was apparently adopted from the work of Pseudo-Isidore, who claimed that this method was routinely used by mariners to produce sweet water from salt water.[35]

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[31] "Showers of milk, blood, flesh, iron,wool and baked tiles," *chapter* 57 in Pliny the Elder, *Natural History 2*.

[32] "Del espacio inferior y los distintos hemisferios," *chapter* 7 in Pseudo-Isidore, *Creaturarum*; Smyth, *Ireland*, p. 193.

[33] "De imbribus," *chapter* 33 in Bede, *De natura rerum*.

[34] "De nubibus" in Bede, *De natura rerum*.

[35] "Del espacio inferior y los distintos hemisferios," in Pseudo-Isidore, *Creaturarum*. Smyth, *Ireland*, pp. 202–203 and 232–233, notes that this question was carefully investigated by Carol Anderson (*Divine Governance, Miracles and Laws of Nature in the Early*

The possible observational basis for a final characteristic of clouds and rain added by Bede—that rain is slow and perennial but rain clouds more swift and sudden—can be evaluated by looking at local weather data. Rainfall occurs on approximately one day in three year-round on the northeast coast of England and can therefore reasonably be described as a perennial condition (figure 5).[36] And the fact that an average day of rain only results in about one fifth of an inch of water (figure 6) supports the idea that rain is slow.[37] However, although clouds that produce rain may appear suddenly (e.g., when a thunderstorm develops), figure 6 indicates that general cloudiness is also perennial; one can expect more than sixty percent of the sky to be covered with clouds on an average day.[38] In this case, one can conclude that the details added by Bede were consistent with his experience of a world that was generally cloudy and often raining moderately but that occasionally produced sudden storms.

Frozen Precipitation: Snow and Hail

Given the right atmospheric conditions, water that condenses to form clouds may precipitate in a solid or earth-like state rather than as liquid water. The possible forms of frozen precipitation include snow, sleet, and hail. Data regarding the frequency of snow and hail in the area around Jarrow can be used to assess the probable influence of personal observations of these phenomena on Bede's adaptations of his source material.

However, it is necessary to begin by noting the potential for confusion inherent in the differing terminologies used in modern English for frozen precipitation. In Amerian English, 'hail' is used exclusively to denote the roughly spherical many-layered balls of ice that are produced when ice crystals falling through thunderclouds are repeatedly caught and lifted by updrafts, gaining an additional layer of ice on each circuit through the cloud, while 'sleet' is used to describe raindrops that are frozen during their descent. In British English, 'hail' may be used to describe either

*Middle Age*s, Ph.D. diss., UCLA, 1982) who was unable to identify any soil that would be capable of desalinating sea water in this way.

[36] See notes 17 and 18.

[37] See notes 17 and 18.

[38] See Table 9. Information obtained from *Climate and Weather*, p. 32.

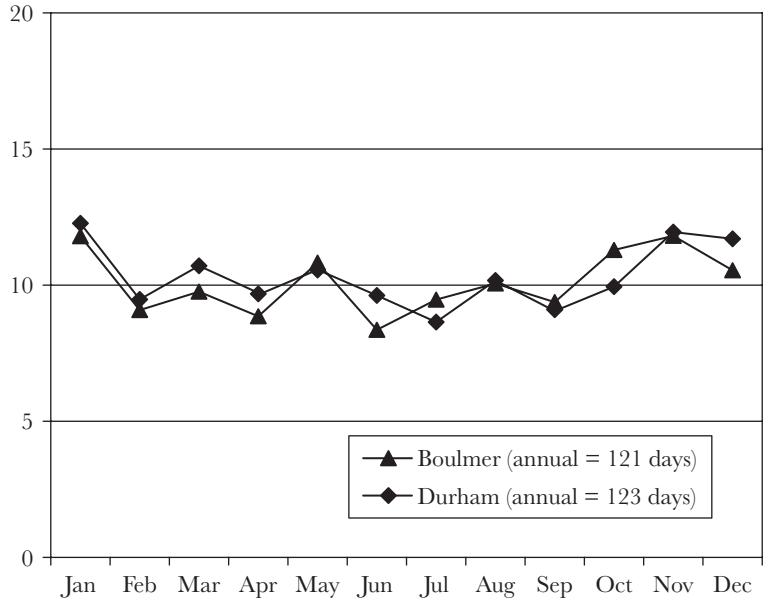

Figure 4. Frequency of rainfall (1961–1990); average number of raindays per month in the region around Jarrow.

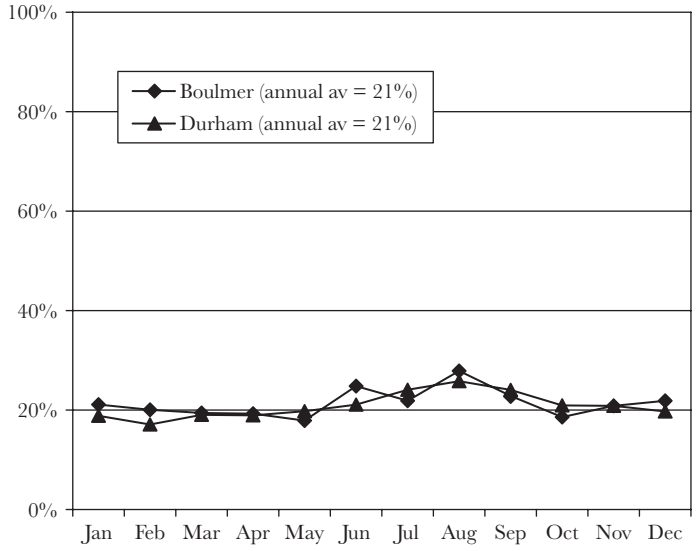

Figure 5. Intensity of rainfall (1961–1990); average depth of rainfall on raindays in the region around Jarrow.

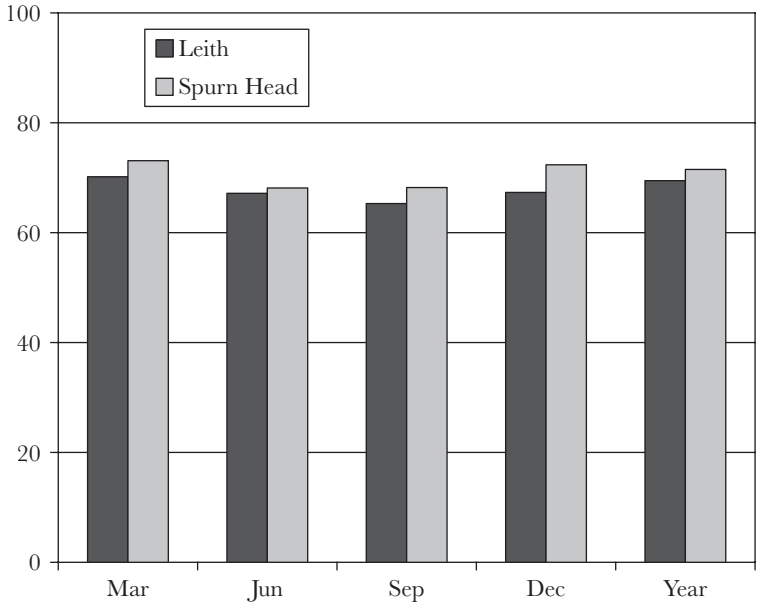

Figure 6. Average cloudiness (1881–1915) on the northeast coast of the UK represented as percent of sky covered. Tynemouth is approximately halfway between Leith (Scotland) and Spurn Head (Yorkshire).

of these while 'sleet' refers to a mixture of rain and melting snow.[39] In contemporary English all seem to agree on the definition of snow: whether single flakes or clumps, snow is made up of hexagonal ice crystals formed when water vapor turns directly to ice without passing through a liquid state. But whether any or all of this is consistent with Northumbrian usage in Bede's time is unknown.

Bede's Mediterranean sources advance a variety of explanations for icy precipitation. Isidore explained the production of frozen precipitation in his *De natura rerum* in two ways. He attributed to Ambrose[40] the claim that waters solidified by the frozen breaths of the winds usually form snow and that this snow falls over the surface of the earth when the atmosphere relaxes. He went on to say without attribution[41] that hail is formed when some of the water in the clouds contracts into ice and then hardens under the harshness of the winds. Once formed, this ice is reduced by wind into small fragments and partially melted by the

[39] Storm Dunlop, *Oxford Dictionary of Weather* (Oxford, 2001), p. 200.
[40] "De la neige" *chapter* 34 in Isidore, *Traité*.
[41] "De la grêle" *chapter* 35 in Isidore, *Traité*.

heat of the sun to fall in pieces to the earth. Isidore noted that some hail is spherical and proposed that this results when the pieces of ice are shaped by the sun's heat and the friction of the air as they travel the long distance from clouds to earth. In his *Etymologies* Isidore added that air may contract to form clouds which may freeze to form snow or (if the clouds are thick and the freezing more disordered) to form hail.[42] According to Pliny[43] there is no doubt that hail is produced by frozen rain while snow is produced by the same fluid less firmly compacted, that snows falls during the winter but hail does not, that hail falls more frequently during the day than at night, and that hail melts more quickly than snow. Pseudo-Isidore explained that snow results when the miniscule water droplets capable of remaining suspended in air are frozen; hail when coalesced droplets are frozen before they have fallen as rain.[44] Bede appears to have extracted ideas from each of these sources but uniquely combined them to claim that grains of hail are formed in the air from drops of rain and frozen by the actions of cold and wind, but that they quickly dissolve into snow.[45] Somewhat contradictorily, he goes on correctly to adopt Pseudo-Isidore's idea that snow is formed when water vapor freezes before it has condensed into liquid droplets.[46] But none of this would have been observable in Bede's time.

However, the occurrence of a given type of frozen precipitation was easily observable. Bede[47] agreed with Pliny[48] that hail falls more frequently during the day than during the night. Hourly data for weather conditions at dozens of stations across the United Kingdom are now available.[49] But given my decision to exclude very recent weather data (see note 15), I will not attempt to assess the accuracy of Bede's statement about diurnal variation in hail frequency for the region around Jarrow. Unlike Pliny[50]—who claimed that snow but not hail falls during

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[42] Translation based on "Del aire y las nubes," *chapter* 7 in Isidore, *Etimologías 13* and Brehaut, *Encyclopedist*, p. 237.

[43] "The nature of hail, snow, hoar, mist, dew; the forms of clouds," *chapter* 61 in Pliny the Elder, *Natural History 2*.

[44] Del espacio inferior y los distintos hemisferios," in Pseudo-Isidore, *Creaturarum*; Smyth, *Ireland*, pp. 212–213.

[45] "De grandine," *chapter* 34 in Bede, *De natura rerum*.

[46] "De nive," *chapter* 35 in Bede, *De natura rerum*.

[47] "De grandine," *chapter* 34 in Bede, *De natura rerum*.

[48] "The nature of hail, snow, hoar, mist, dew; the forms of clouds," in Pliny the Elder, *Natural History 2*.

[49] http://www.met-office.gov.uk/education/data/uk_map.html.

[50] "The nature of hail, snow, hoar, mist, dew; the forms of clouds," in Pliny the Elder, *Natural History 2*.

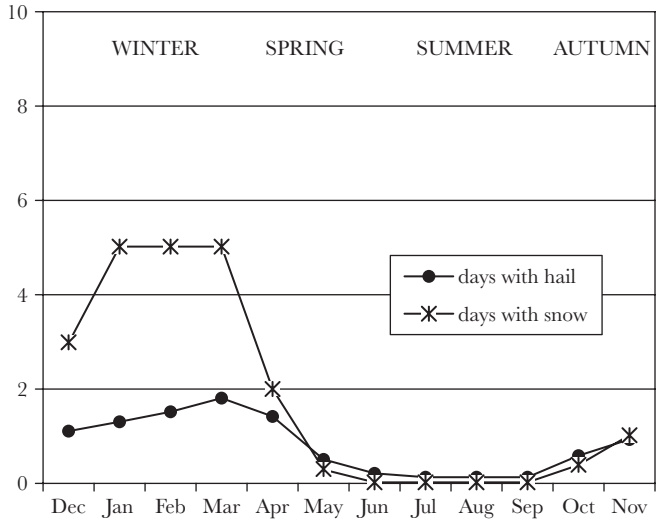

Figure 7. Average monthly frozen precipitation (1881–1915); snow and hail at Tynemouth.

the winter—Bede did not comment on seasonal variation in snow or hail. Data from the region around Jarrow collected between 1881 and 1915[51] (see figure 7) suggest that Bede had good reason not to repeat Pliny's claim that only snow falls during the winter. The data also demonstrate that hail (at least in the British sense) is far more frequent during the winter than during the summer.

Without more information, it is not possible to assess the accuracy of Bede's mysterious assertion[52] that snow does not fall on the deep sea. However, there is no reason to believe that Bede ever traveled far from his birthplace and it is likely that this statement was based on the reports of others rather than on his own experience.

Why the Sea does not Grow and Why it is Salty

Water completes its movement through the hydrologic cycle when the droplets that fall as precipitation reunite and eventually find their way—underground or in surface channels—back to the salty seas. In everyday experience, rivers can be observed to pour substantial volumes

[51] See Tables 34 and 36. Information obtained from *Climate and Weather*, pp. 85, 87.
[52] "De nive," *chapter* 35 in Bede, *De natura rerum*.

of fresh water into the sea and so it is natural to ask why the level of the sea does not rise and why its waters do not become less salty with the passage of time. The location of the monastery at Jarrow provided the opportunity for daily observation of this phenomenon.

Isidore's *De natura rerum* offered two possible explanations for the apparently constant volume of the sea.[53] He attributed the first explanation, that the sea is so vast that it can absorb the water contributed by all the world's rivers without visible effect, to Bishop Clemens.[54] However, he added that the evaporative power of sun and wind is also a factor and pointed out that lakes and ponds could be seen to dry up under their influence. His second explanation, that rivers sometimes return to the places from which they flow out, was attributed to Salomon.[55] Isidore went on to explain in his *Etymologies*[56] as well as in *De natura rerum* that conduits hidden in the depths of the sea allow river waters to flow back towards their sources where they are reintroduced into their habitual channels. This explanation was also put forward by Pliny.[57] (Pseudo-Isidore's discussion of the sea was limited to tides, the sea as a travel route, and the sea as the source of aquatic and avian life.)[58]

Bede[59] condensed but essentially repeated both of Isidore's explanations. In fact, the North Sea is not vast enough to absorb all of the water that flows into it without visible effect. If all the river water that flowed in, directly or via rivers emptying into the Baltic, remained in the North Sea, its water level would rise by approximately one meter per year.[60] But the combined effects of ocean currents and evaporation

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[53] "Pourquoi la mer ne croît point," *chapter* 41 in Isidore, *Traité*.

[54] "The vast unmeasurable sea, gathered together by His working into various basins, never passes beyond the bounds placed around it, but does as He has commanded," First Epistle of Clement to the Corinthians, ed. and trans. by Philip Schaff (Wm.B. Eerdmans Publishing Company, reprint 2001). Digital version available at http://www.ccel.org/ccel/schaff/anf01.html

[55] This variant spelling was used consistently in the text of Isidore's *De natura rerum* that was translated by Fontaine in *Traité*. In this case, Isidore's attribution appears to be erroneous. The passage quoted by Isidore, "ad locum unde exeunt flumina reuertuntur" actually appears to derive from Ecceles. 1:7, "omnia flumina intrant mare et mare non redundat ad locum unde exeunt flumina revertuntur ut iterum fluant" in the Vulgate of Jerome. Digital version available at http://www.fourmilab.ch/etexts/www/Vulgate/Ecclesiastes.html.

[56] Translation based on "Del mar," *chapter* 14 in Isidore, *Etimologías 13* and Ernest Brehaut, *Encyclopedist*, p. 241.

[57] "How the water is connected with the earth; Of the navigation of the sea and the rivers," *chapter* 66 in Pliny the Elder, *Natural History* 2.

[58] "De la naturaleza de las aguas y del movimento del océano," *chapter* 9 in Pseudo-Isidore, *Creaturarum*.

[59] "Cure mare non crescat," chapter 40 in Bede, *De natura rerum*.

[60] http://www.mumm.ac.be/EN/NorthSea/facts.php.

keep mean sea level approximately constant. The erroneous idea that sea water returns via hidden conduits from the depths of the sea to rivers' sources, perhaps because it could be neither confirmed nor refuted by direct observation and because water does flow underground, was shared by natural philosophers who considered the phenomenon of springs for many centuries[61] after Bede wrote his *De natura rerum*.

After this initial agreement, Isidore's and Bede's explanations for the constant volume of the sea diverged. According to Isidore[62] the sea exists to receive the waters of all the rivers; it is of variable depth but has a uniformly flat surface; the naturalists (*physici*) say that the surface of the sea is higher than the surface of the land. Bede omitted all three of these claims but added the apparently unique idea that fresh waters, being lighter than salt water, remain and spread on the surface of the sea.

Bede's omission of Isidore's comment about the purpose of the sea was consistent with his practice throughout. Given that he lived beside a tidal estuary where large areas of nearby land were alternately submerged and above water, it is not surprising that he might be reluctant to make a definitive statement about the relative levels of land and sea. (His later work demonstrated a life-long interest in tides.)[63] Perhaps the idea that the depth of the sea varies while its surface is flat seemed too obvious to someone living his life near the sea to be worth mentioning.

Bede's concept of fresh water floating on salt water exemplifies, again, his focus on the relative heaviness of the constituents of the natural environment, but the source of this idea is unclear. While the density of water does increase with salt content (assuming a constant water temperature), the relatively shallow and well-mixed water in the Tyne and Wear estuaries and along the nearby coastline would probably not have provided observable examples of this. At present, there is a pronounced salinity gradient, with lighter, fresher water at the surface, in the deepest parts of the North Sea, e.g., off the west coast of Norway. However, this gradient disappears as one approaches the much shallower region along the east coast of the British Isles. Along this coast, the sea is essentially as salty at its surface as it is at the bottom depth

[61] Pierre Perrault, *On the Origin of Springs*, trans. Aurele LaRocque, (New York, 1967), p. 123.
[62] "Pourquoi la mer ne croît point" in Isidore, *Traité*.
[63] Wallis, *Reckoning*, pp. 307–312.

of 250 meters near Norway.[64] Nor is this idea of Bede's consistent with Pliny, who agreed that the fire of the sun evaporates lighter fresh water, leaving the heavier acrid components of the sea behind[65] but who concluded that this would lead to higher salinity at the surface of the sea than at greater depths. And while Isidore's *Etymologies* pointed out that many other substances in addition to salt could be found in natural water bodies[66] and that only those bodies that are salty can properly be called seas,[67] he did not refer to the relative heaviness or position of various waters.

Isidore[68] and Bede[69] reiterated some of these arguments in their discussions of the reasons for the persistent bitterness of sea water. In this case, Isidore attributed the idea, namely that the quantity of fresh water lost to evaporation each day is equal to the input of rivers, to "the ancients" via Ambrose. Bede repeated the evaporation/distillation argument discussed in the section above on clouds and rain but added that the waters left behind are heavier and sink because the surface of sea water is sweeter than the waters of the abyss. Bede's additional contributions on this topic were his idea that the sea is fed by rains as well as by rivers –easily observable by someone living near the coast of the Mediterranean or of the North Sea—and his claim that fresh waters "nourish the moon" while sea waters "nourish the sun." The source for the later statement—atypical for Bede's *De natura rerum* in that its physical significance is not obvious—appears to come directly from Pliny.[70]

Conclusion

Some of the changes that Bede made when adapting Isidore's *De natura rerum* for his students seem to be based on observable characteristics of the physical environment of a tidal estuary on the northeast coast of England. These include the year-round persistence of light to moderate rainfall, the rapid development of storm clouds, and the occurrence

[64] http://www.ospar.org/eng/doc/pdfs/R2C2.pdf.
[65] "Why the sea is salt," chapter 104 in Pliny the Elder, *Natural History 2*.
[66] "Sobre la diversidad de las aquas," chapter 13 in Isidore, *Etimologías 13*.
[67] "Del mar" in Isidore, *Etimologías 13*.
[68] "Pourquoi la mer a des eaux ameres," chapter 42 in Isidore, *Traité*.
[69] "Cur sit amarum," chap 41 in Bede, *De natura rerum*.
[70] "Why the sea is salt" in Pliny the Elder, *Natural History* 2.

of frozen precipitation that is not snow during the winter. However, other changes are not explainable in that way. For example, there does not seem to be an observational basis for claiming—even though these claims may be correct—that snow forms when vapor is frozen, that salt water can be transformed to fresh by pouring it through soil, or that fresh water from rivers floats atop the salty water of the sea.

There is much additional work to be done before we can definitively assess the degree to which Bede's *De natura rerum* was affected by his personal observations. Future work will extend the analysis to additional hydrologically-based and atmospheric phenomena. Hydrologic and atmospheric topics that remain to be analyzed include the causes, names, and properties of winds,[71] earthbound water,[72] the dual nature of water,[73] the air,[74] thunder and lightning,[75] rainbows,[76] and weather prediction.[77] It will also be useful to consider sections of Bede's *De natura rerum* that deal with astronomical phenomena that might be observably affected by differences in latitude.

[71] "De ventis" and "Ordo ventorum," chapters 26 and 27 in Bede, *De natura rerum*.
[72] "Aquis terram necti," chapter 44 in Bede, *De natura rerum*.
[73] "De natura aquarum duplici," chapter 38 in Bede, *De natura rerum*.
[74] "De aere," chapter 25 in Bede, *De natura rerum*.
[75] "De tonitruo" and "De fulminibus," chapters 28 and 29 in Bede, *De natura rerum*.
[76] "De arcu cœli," chapter 31 in Bede, *De natura rerum*.
[77] "Signa tempestatum vel serenitatis," chapter 37 in Bede, *De natura rerum*.